

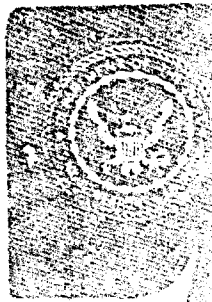
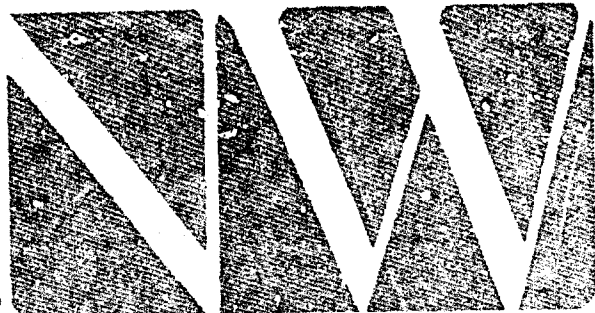
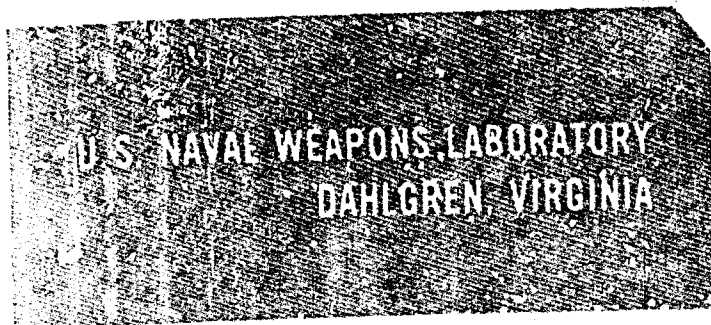
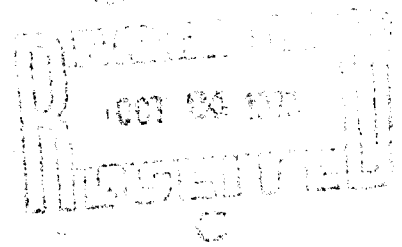
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**A COMPUTER PROGRAM TO CALCULATE THERMAL
AND BALLISTIC PROPERTIES OF SOLID PROPELLANTS**

William J. Brown



NWL Technical Report No. TR-3007
July 1973

**A COMPUTER PROGRAM TO CALCULATE THERMAL AND
BALLISTIC PROPERTIES OF SOLID PROPELLANTS**

by

William J. Brown

Engineering Department

Distribution limited to U. S. Government agencies only; Test and Evaluation: July 1973. Other requests for this document must be referred to Commander, Naval Weapons Laboratory, Dahlgren, Virginia 22448.

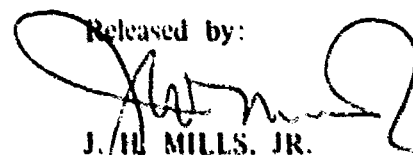
FOREWORD

The work covered in this report is part of a continuing effort to increase reliability and reduce the development time and cost of Navy cartridges and cartridge actuated devices for aircraft systems. These aims are met, in part, by using state-of-the-art techniques in interior ballistics and computer technologies to conserve time and materials.

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ABSTRACT

This report describes a computer program written to calculate ballistic and thermal properties of solid propellants using the method of additive constants. A program listing and sample output are included.

CONTENTS

	Page
FOREWORD	i
ABSTRACT	ii
I. INTRODUCTION	1
II. THE ADDITIVE CONSTANTS	2
III. THE THERMAL PROPERTIES	6
IV. THE COMPUTER PROGRAM	7
V. PROGRAM LISTING	8
VI. ADDITIVE CONSTANTS STORED IN THE PROGRAM	13
VII. PROGRAM OUTPUT FOR ALL PROPELLANTS RUN TO DATE	15
A. HES 4831.9B	15
B. HES 5130	16
C. HES 5250.86	17
D. HES 5250.87	18
E. HES 5250.94	19
F. HES 5250.95	20
G. HES 5250.96	21
H. HES 5250.200	22
I. HES 5250.201	23
J. HES 5250.202	24
K. HES 5250.203	25
L. HES 5354.26A	26
M. HIVEL # 2	27
N. IMR 5010	28
O. IND 7199	29
P. M-2	30
Q. M-5	31
R. N-4	32
S. NPFB 292	33
T. PYROCELLULOSE	34
U. SPDN 8880	35
V. SPDN 9373	36
W. UNIQUE (ALSO BULLSEYE)	37
VIII. RECOMMENDATIONS	38
IX. BIBLIOGRAPHY	39
APPENDIX	
A. DISTRIBUTION	

I. INTRODUCTION

The Naval Weapons Laboratory employs mathematical modeling, or computer simulation, of cartridge actuated devices (CADs) to optimize their design in an efficient and timely manner. A good CAD simulation must contain reasonably accurate estimates of the ballistic properties of the propellant used. Most of these ballistic properties are calculated from the chemical constituents of the propellant, Reference 1. A form that simplifies the computation of these ballistic properties has been developed. However, the calculation, though simplified and done on a high-speed desk calculator, is still tedious and time consuming. The method was computerized and now it is only necessary to enter the percent of each chemical constituent, and the computer prints out a standard format containing all the required information.

II. THE ADDITIVE CONSTANTS

Table 1 shows the form used to calculate the covolume of the propellant. The first column, c'_i , is the number of parts of each constituent. The bottom entry in that column, Σ , is the total number of parts.

The second column, c_i , is the number of parts of each constituent divided by $\Sigma c'_i$ (bottom entry in first column). The last entry in the second column is the total of that column and should equal (or very nearly equal) one.

The third column is the number of moles of gas for each constituent. It is calculated by means of the equation:

$$n_i = (C_i) + \frac{1}{2}(H_i) + \frac{1}{2}(N_i) .$$

C_i , H_i , and N_i may be calculated as in the following example. For ethyl alcohol, C_2H_5OH :

$$\begin{aligned} C_2 &= 2(12.011) = 24.022 \\ H_6 &= 6(1.008) = 6.048 \\ O_1 &= 1(16.000) = \underline{16.000} \\ \text{SUM} &= 46.070 \end{aligned}$$

(The numbers in parentheses are atomic weights of the constituents.) Then:

$$\begin{aligned} C_i &= 2/46.07 = 0.043412 \\ H_i &= 6/46.07 = 0.130237 \\ N_i &= 0/46.07 = 0.0 \end{aligned}$$

Then $c_i \cdot n_i = N$, where c_i is the value from column 2 for each constituent. The last entry in the third column is the column total.

The fourth column contains the mean heat capacity, C_{v_i} , for each constituent multiplied by its quantity (c_i , column 2).

$$C_v = 1.803(C_i) + 3.264(H_i) + 5.008(O_i) + 3.328(N_i) .$$

O_i is calculated in the same manner as C_i , H_i , and N_i above. The last entry in column 4 is the column total.

The fifth column contains the energy released, E_i , for each constituent again multiplied by its c_i from column 2.

$$E_i = -E(1)_i - 38966(C_i) - 6252(H_i) + 52073(O_i) - 6721(N_i) .$$

$E(1)_i$ is the energy of formation at 15°C for each constituent and may be obtained from tabular data in Reference 2.

The sixth column contains the covolume, η_i , for each constituent multiplied by its c_i . The covolume, η_i , may be calculated as follows. For nitroglycerine, $\text{C}_3\text{H}_5(\text{ONO}_2)_3$:

$$\begin{aligned} C_3 &= 3(12.011) = 36.033 \\ H_5 &= 5(1.008) = 5.040 \\ O_9 &= 9(16.000) = 144.000 \\ N_3 &= 3(14.008) = \underline{42.024} \\ &227.097 \end{aligned}$$

Then,

$$\eta_i = 1.18 + 6.9(C_i) - 11.5(O_i)$$

Hence,

$$C_i = \frac{3}{227.097} = 0.01321$$

$$O_i = \frac{9}{227.097} = 0.03963$$

and

$$\begin{aligned}\eta_i &= 1.18 + 6.9(0.01321) - 11.5(0.03963) \\ &= 0.81540 \text{ cm}^3/\text{gm} \\ &= 22.57 \text{ in}^3/\text{lb}\end{aligned}$$

The final entry in the column is the column total and represents the covolume of the propellant.

TABLE 1

**PROPELLANT COMPOSITION AND THERMODYNAMIC AND
BALLISTIC PROPERTIES OF COMBUSTION PRODUCTS**

Component	c'_i	c_i	$\frac{N}{\text{gm-moles}} \text{ gm}$	$\frac{C_v}{(\text{gm})\text{cal}} \text{ gm-}^\circ\text{k}$	$\frac{E}{(\text{gm})\text{cal}} \text{ gm}$	$\frac{\eta}{\text{in}^3} \text{ lb}_m$
	Parts	$\frac{c'_i}{\sum c'_i}$	$c_i n_i$	$c_i C_{v_i}$	$c_i E_i$	$c_i \eta_i$
Nitrocellulose (13.25 % N)	58.50	0.5821	0.0199	0.1970	+170.55	16.05
Alcohol						
Water						
DPA						
DNT	2.50	0.0249	0.0015	0.0080	-16.64	1.01
DBP						
Nitroglycerin	22.50	0.2239	0.0069	0.0758	+213.04	5.10
Ethyl Centralite	8.50	0.0846	0.0088	0.0339	243.82	5.26
Triacetin	8.00	0.0796	0.0058	0.0334	157.03	3.48
Lead Stearate	0.50	0.0049	0.0006	0.0028	18.26	0.20
Σ	100.50	1.0000	0.0435	0.3509	52.16	31.10

III. THE THERMAL PROPERTIES

Propellant thermal properties may now be calculated from the additive constants developed in the previous section.

Adiabatic Flame Temperature (T_v)

$$T_v = 2,500 + \frac{\sum c_i E_i}{\sum c_i C_{v_i}} (^{\circ}\text{K})$$

Moles of gas per gram (N)

$$N = \sum c_i n_i \text{ (moles/gram)}$$

Impetus (F)

$$F = 2.782NT_v \text{ (ft-lb/lb)}$$

Heat Capacity (C_v)

$$C_v = 1.400 \sum c_i C_{v_i} \frac{\text{ft-lb}}{\text{lb} \cdot ^{\circ}\text{K}}$$

Ratio of Specific Heats (γ)

$$\gamma = 1 + \frac{2.782N}{C_v} \text{ (no units)}$$

Covolume (η)

$$\eta = \sum c_i \eta_i \text{ (in}^3\text{/lb)}$$

IV. THE COMPUTER PROGRAM

The foregoing method was programmed in basic language to be run on a time-shared computer. A minor modification was made to the method previously described, in that a linear interpolation was used to determine the additive constants for the different percent values of nitrogen in nitrocellulose. The relationships used are:

$$n_1 = -0.0021815 (\%N) + 0.067867$$

$$C_{v_1} = -0.0063690 (\%N) + 0.422860$$

$$E_1 = 143.8200000 (\%N) - 1,612.400000$$

$$\eta_1 = -1.0000000 (\%N) + 40.710000$$

The agreement between the above relationships and tabulated values obtained by other methods is very good. Thus, nitrocellulose containing any (reasonable) percent nitrogen may be handled by the program.

Values of zero are stored in the data matrix for nitrocellulose, and the linear interpolations described above are used in their place.

V. PROGRAM LISTING

```

100=100REM NWBBCON 19JAN72 PROPELLANT CONSTANTS (WJB65).
110=110REM
120=120REM Z=0 COMPUTES; Z=1 LISTS INPUT CONSTANTS.
130=130Z=0
140=140GOTO220
150=150REM ENTER NAME OF PROPELLANT ON NEXT LINE.
160=160PRINT"PROPELLANT NAME SHOULD BE ON THIS LINE."
170=170PRINT
180=180REM ENTER PERCENT N IN NITROCELLULOSE ON NEXT LINE.
190=190P=0
200=200REM
210=210GOTO290
220=220IFZ=1THEN290
230=230PRINT"."
240=240PRINT""
250=250FORN=1TO5
260=260PRINT
270=270NEXTN
280=280GOTO150
290=290DIMA(64),BS(64),C(64),D(64),E(64),F(64),G(64),H(64),I(64)
300=300DIMJ(64),K(64),L(64),M(64)
310=310Y=64
320=320FORN=1TO64STEP2
330=330A(N)=N
340=340NEXTN
350=350BS(1)="ACETONE"
360=360BS(2)=" "
370=370BS(3)="ACETYLENE"
380=380BS(4)=" "
390=390BS(5)="AMMONIUM NITRA"
400=400BS(6)="TE"
410=410BS(7)="BARIUM NITRATE"
420=420BS(8)=" "
430=430BS(9)="BASIC LEAD CAR"
440=440BS(10)="BONATE"
450=450BS(11)="BUTYL STEARATE"
460=460BS(12)=" "
470=470BS(13)="DIAMYL PHTHALA"
480=480BS(14)="TE"
490=490BS(15)="DIBUTYL PHTHAL"
500=500BS(16)="ATE"
510=510BS(17)="DIETHYL PHTHAL"
520=520BS(18)="ATE"
530=530BS(19)="DINITROTOLUENE"
540=540BS(20)=" "
550=550BS(21)="DI-OCTYL PHTHAL"
560=560BS(22)="ATE"
570=570BS(23)="DIPHENYLAMINE"
580=580BS(24)=" "
590=590BS(25)="ETHYL ALCOHOL"
600=600BS(26)=" "

```

610=610BS(27)="ETHYL CENTRAL I"
 620=620BS(28)="TE, CARBAMITE"
 630=630BS(29)="GRAPHITE"
 640=640BS(30)=" "
 650=650BS(31)="LEAD STEARATE"
 660=660BS(32)=" "
 670=670BS(33)="METHYL CENTRAL"
 680=680BS(34)="ITE"
 690=690BS(35)="NITROCELLULOSE"
 700=700BS(36)=" "
 710=710BS(37)="2-NITRODIPHENY"
 720=720BS(38)="LAMINE"
 730=730BS(39)="NITROGLYCERINE"
 740=740BS(40)=" "
 750=750BS(41)="NITROGUANADINE"
 760=760BS(42)=", PICKRITE"
 770=770BS(43)="PETN"
 780=780BS(44)=" "
 790=790BS(45)="PETROLATUM, MI"
 800=800BS(46)="NERAL JELLY"
 810=810BS(47)="POTASSIUM NITR"
 820=820BS(48)="ATE"
 830=830BS(49)="POTASSIUM SULP"
 840=840BS(50)="HATE"
 850=850BS(51)="RDX"
 860=860BS(52)=" "
 870=870BS(53)="TRIACETIN"
 880=880BS(54)=" "
 890=890BS(55)="TRINITROTOLUEN"
 900=900BS(56)="E"
 910=910BS(57)="VASELINE"
 920=920BS(58)=" "
 930=930BS(59)="WATER"
 940=940BS(60)=" "
 950=950BS(61)="CELLULOSE ACET"
 960=960BS(62)="ATE"
 970=970BS(63)="CARBON"
 980=980BS(64)=" "
 990=990FORN=1TOYSTEP2
 1000=1000C(N)=0
 1010=1010NEXTN
 1020=1020REM ENTER C(N) VALUES AFTER THIS LINE.
 1030=1030FORN=2TOYSTEP2
 1040=1040IFC(N)=0THEN1080
 1050=1050PRINT"VALUE ENTERED FOR EVEN C(N); CORRECT AND RERUN",
 1060=1060PRINT" PROGRAM."
 1070=1070STOP
 1080=1080NEXTN
 1090=1090IFP=0THEN1140
 1100=1100IFC(35)<>0THEN1200
 1110=1110PRINT"PERCENT N ENTERED FOR P, BUT NO C(35); CORRECT AND",

```

1120=1120PRINT"RERUN PROGRAM."
1130=1130STOP
1140=1140IFC(35)=0THEN1200
1150=1150IFZ=1THEN1200
1160=1160IFP<>0THEN1200
1170=1170PRINT"YOU DID NOT ENTER PERCENT N FOR NITROCELLULOSE.",
1180=1180PRINT" ENTER P AND RERUN PROGRAM."
1190=1190STOP
1200=1200FORN=1TOYSTEP2
1210=1210READA(N),D(N),E(N),F(N),G(N)
1220=1220NEXTN
1230=1230PRINT
1240=1240IFZ<->1THEN1350
1250=1250PRINT"CONSTITUENT","NI","CVI","EI","ETAI"
1260=1260PRINT
1270=1270FORN=1TOYSTEP2
1280=1280IFN<->35THEN1310
1290=1290PRINTBS(N),"VALUES COMPUTED BASED ON PERCENT N"
1300=1300GOTO1320
1310=1310PRINTBS(N),D(N),E(N),F(N),G(N)
1320=1320PRINTBS(N+1)
1330=1330NEXTN
1340=1340GOTO1340
1350=1350FORN=1TOYSTEP2
1360=1360C=C+C(N)
1370=1370NEXTN
1380=1380IFC(35)=0THEN1430
1390=1390D(35)=-2.1815E-3*P+6.7867E-2
1400=1400E(35)=-6.369E-3*P+0.42286
1410=1410F(35)=143.82*P-1612.4
1420=1420G(35)=-1*P+40.71
1430=1430FORN=1TOYSTEP2
1440=1440H(N)=C(N)/C
1450=1450NEXTN
1460=1460FORN=1TOY
1470=1470H=H+H(N)
1480=1480NEXTN
1490=1490FORN=1TOYSTEP2
1500=1500IFC(N)=0THEN1590
1510=1510IFN<->35THEN1560
1520=1520M(N)=INT(10000*K(N)+0.5)/10000
1530=1530PRINT100*M(N),"PERCENT ",BS(N),BS(N+1),P,"PERCENTN"
1540=1540PRINT
1550=1550GOTO1590
1560=1560M(N)=INT(10000*H(N)+0.5)/10000
1570=1570PRINT100*M(N),"PERCENT ",BS(N),BS(N+1)
1580=1580PRINT
1590=1590NEXTN
1600=1600M=INT(10000*H+0.5)/10000
1610=1610PRINT100*M,"PERCENT ","TOTAL"
1620=1620PRINT

```

```

1630=1630PRINT
1640=1640FØRN=1TØYSTEP2
1650=1650I(N)=D(N)*H(N)
1660=1660NEXTN
1670=1670FØRN=1TØYSTEP2
1680=1680I=I+I(N)
1690=1690NEXTN
1700=1700FØRN=1TØYSTEP2
1710=1710J(N)=E(N)*H(N)
1720=1720NEXTN
1730=1730FØRN=1TØYSTEP2
1740=1740J=J+J(N)
1750=1750NEXTN
1760=1760FØRN=1TØYSTEP2
1770=1770K(N)=F(N)*H(N)
1780=1780NEXTN
1790=1790FØRN=1TØYSTEP2
1800=1800K=K+K(N)
1810=1810NEXTN
1820=1820FØRN=1TØYSTEP2
1830=1830L(N)=G(N)*H(N)
1840=1840NEXTN
1850=1850FØRN=1TØYSTEP2
1860=1860L=L+L(N)
1870=1870NEXTN
1880=1880T=250)+K/J
1890=1890F=2782*I*T
1900=1900M=1+(2782*I)/(1400*J)
1910=1910PRINT"TV=";T;"DEGREES K"
1920=1920PRINT
1930=1930PRINT"N ";I;"MOLES/GRAM"
1940=1940PRINT
1950=1950PRINT"F=";F;"FT-LT/LB"
1960=1960PRINT
1970=1970PRINT"CV=";1400*J;"FT-LB/LB-DEG K"
1980=1980PRINT
1990=1990PRINT"GAMMA=";M
2000=2000PRINT
2010=2010PRINT"ETA=";L;"CU-IN/LB"
2020=2020DATA1,0.10336,0.5107,-2842.5,57.22
2030=2030DATA3,0.11532,0.3755,-1374.69.3
2040=2040DATA5,0.03748,0.4424,405.1,22.83
2050=2050DATA7,0.00765,0.1374,131.15.34
2060=2060DATA9,0.00387,0.091,-199.7,10
2070=2070DATA11,0.12919,0.5675,-3726.43.15
2080=2080DATA13,0.1013,0.4408,-3.49.5,58.81
2090=2090DATA15,0.097,0.4325,-2691.56.97
2100=2100DATA17,0.0865,0.3931,-2242.37.25
2110=2110DATA19,0.05039,0.3239,-643.7,40.44
2120=2120DATA21,0.1101,0.4796,-3101.60
2130=2130DATA23,0.10636,0.36,-3007.65.44

```

2140=2140DATA25,0.10853,0.6121,-2772,56.35
2150=2150DATA27,0.10434,0.4013,-2882,62.6
2160=2160DATA29,0.08326,0.1349,-3234,60.45
2170=2170DATA31,0.12245,0.5714,-3726.5,40
2180=2180DATA33,0.10222,0.3987,-2833,43.44
2190=2190DATA35,0,0,0,0
2200=2200DATA37,0.08402,0.3317,-1949,66
2210=2210DATA39,0.03082,0.3388,951.5,22.78
2220=2220DATA41,0.04804,0.369,-57.4,31.77
2230=2230DATA43,0.0348,0.3485,724.1,24.88
2240=2240DATA45,0.1451,0.6128,-4113,65.64
2250=2250DATA47,0.00989,0.2158,25,23.61
2260=2260DATA49,-0.00574,0.2708,-662.4,9.36
2270=2270DATA51,0.04052,0.3391,639,28.51
2280=2280DATA53,0.07333,0.4191,-1972.8,43.77
2290=2290DATA55,0.0484,0.3035,-110.1,34.31
2300=2300DATA57,0.142,0.5983,-4175.1,65.65
2310=2310DATA59,0.05551,0.6403,-1552.2,24.6
2320=2320DATA61,0.06944,0.11735,2722.72,31.776
2330=2330DATA63,0.08326,0.1349,-3234,60.45
2340=2340END

VI. ADDITIVE CONSTANTS STORED IN THE PROGRAM

CONSTITUENT	NI	CVI	EI	ETA1
ACETONE	.10336	.5107	-2842.5	57.22
ACETYLENE	.11532	.3755	-1374	69.3
AMMONIUM NITRATE	.03748	.4424	405.1	22.83
BARIUM NITRATE	.00765	.1574	131	15.34
BASIC LEAD CARBONATE	.00387	.091	-199.7	10
BUTYL STEARATE	.12919	.5675	-3726	43.15
DIAMYL PHTHALATE	.1013	.4408	-3149.5	58.81
DISBUTYL PHTHALATE	.097	.4336	-2691	56.97
DIETHYL PHTHALATE	.0865	.3931	-2242	37.25
DINITROTOLENE	.06039	.3239	-648.7	40.44
DIOCTYL PHTHALATE	.1101	.4796	-3101	60
DIPHENYLAMINE	.10636	.36	-3007	65.44
ETHYL ALCOHOL	.10853	.6121	-2772	56.35
ETHYL CENTRALITE, CARBAMITE	.10434	.4013	-2882	62.6
GRAPHITE	.08326	.1349	-3234	60.45
LEAD STEARATE	.12245	.5714	-3726.5	40
METHYL CENTRALITE	.10222	.3987	-2833	43.44
NITROCELLULOSE VALUES COMPUTED BASED ON PERCENT N				
2-NITRODIPHENYLAMINE	.08402	.3317	-1949	66
NITROGLYCERINE	.03082	.3388	951.5	22.78
NITROGUANADINE, PICHITE	.04804	.369	-57.4	31.77
PETN	.0348	.3485	724.1	24.68
PETROLATUM, H1	.1451	.6128	-4113	65.64
NERAL JELLY				
POTASSIUM NITRATE	.00989	.2158	25	23.61

..

CONSTITUENT	NI	CVI	EI	ETAI
POTASSIUM SULP-	.00574	.2708	-662.4	9.36
MATE				
RDX	.04052	.3391	639	28.51
TRIACETIN	.07333	.4191	-1972.8	43.77
TRINITROTOLUEN	.0484	.3035	-110.1	34.31
E				
VASELINE	.142	.5983	-4175.1	65.65
WATER	.05551	.6403	-1552.2	24.6
CELLULOSE ACET	.06944	.11735	2722.72	31.776
ATE				
CARBON	.08326	.1349	-3234	60.45

..

VII. PROGRAM OUTPUT FOR ALL PROPELLANTS RUN TO DATE

HES 4831.9B (ALSO SEE H1VEL: #2 AND M2)

1.5	PERCENT BARIUM NITRATE
.6	PERCENT ETHYL CENTRALITE CARBAMITE
.25	PERCENT GRAPHITE
77.35	PERCENT NITROCELLULOSE 13.15 PERCENT N
19.5	PERCENT NITROGLYCERINE
.8	PERCENT POTASSIUM NITRATE
100	PERCENT TOTAL

TV= 3627.71 DEGREES K

N= 3.70439E-2 MOLES/GRAM

F= 376886. FT-LB/LB

CV= 469.278 FT-LB/LB-DEG K

GAMMA= 1.22138

ETA= 26.7055 CU-IN/LB

HES 5130

2.49	PERCENT DINITROTOLUENE	
8.46	PERCENT ETHYL CENTRALITE, CARBAMITE	
.5	PERCENT LEAD STEARATE	
58.2	PERCENT NITROCELLULOSE	13.25 PERCENT N
22.39	PERCENT NITROGLYCERINE	
7.96	PERCENT TRIACETIN	
100	PERCENT TOTAL:	

TV= 2352.14 DEGREES K

N= .046356 MOLES/GRAM

F= 303338. FT-LB/LB

CV= 491.51 FT-LB/LB-DEG K

GAMMA= 1.26238

ETA= 31.0688 CU-IN/LB

..

HES 5250.86 (ALSO HES 4100.27 AND HPC-86)

1.5	PERCENT BARIUM NITRATE
.6	PERCENT ETHYL CENTRALITE CARBAMITE
.25	PERCENT GRAPHITE
69.35	PERCENT NITROCELLULOSE 13.25 PERCENT N
19.5	PERCENT NITROGLYCERINE
.8	PERCENT POTASSIUM NITRATE
8.	PERCENT CELLULOSE ACETATE
100	PERCENT TOTAL

TV= 4340.56 DEGREES K

N= 3.96134E-2 MOLES/GRAM

F= 478351. FT-LB/LB

CU= 443.822 FT-LB/LB-DEG K

GAMMA= 1.24331

ETA= 26.9734 CU-IN/LB

..

HES 5250.87 (ALSO HES 4100.29 AND HPC-87)

1.	PERCENT BARIUM NITRATE	
6.5	PERCENT ETHYL CENTRALITE, CARBAMITE	
.2	PERCENT GRAPHITE	
71.3	PERCENT NITROCELLULOSE	13.25 PERCENT N
20.	PERCENT NITROGLYCERINE	
1.	PERCENT POTASSIUM NITRATE	
100	PERCENT TOTAL	

TV= 3110.67 DEGREES K

N= .041068 MOLES/GRAM

F= 355398. FT-LB/LB

CV= 474.846 FT-LB/LB-DEG K

GAMMA= 1.24061

ETA= 28.7144 CU-IN/LB

..

HES 5250.94

2.5	PERCENT DINITROTOLUENE		
8.	PERCENT ETHYL CENTRALITE, CARBAMITE		
.5	PERCENT LEAD STEARATE		
58.5	PERCENT NITROCELLULOSE	13.25	PERCENT N
22.5	PERCENT NITROGLYCERINE		
8.	PERCENT TRIACETIN		
100	PERCENT TOTAL		

TV= 2392.78 DEGREES K

N= 4.60629E-2 MOLES/GRAM

F= 306628. FT-LB/LB

CV= 491.151 FT-LB/LB-DEG K

GAMMA= 1.26091

ETA= 30.9102 CU-IN/LB

..

HES 5250.95 (ALSO HPC-95)

.75	PERCENT DIPHENYLAMINE
.25	PERCENT GRAPHITE
78.	PERCENT NITROCELLULOSE 13.25 PERCENT N
20.	PERCENT NITROGLYCERINE
1.	PERCENT POTASSIUM SULPHATE
100	PERCENT TOTAL

TV= 3631.06 DEGREES K

N= 3.75029E-2 MOLES/GRAM

F= 378640. FT-LB/LE

CV= 472.517 FT-LB/LB-DEG K

GAMMA= 1.2208

ETA= 26.7103 CU-IN/LB

..

HES 5250.96

1.5	PERCENT BARIUM NITRATE
.65	PERCENT ETHYL CENTRALITE, CARBAMITE
.2	PERCENT GRAPHITE
76.85	PERCENT NITROCELLULOSE 13.25 PERCENT N
20.	PERCENT NITROGLYCERINE
.8	PERCENT POTASSIUM NITRATE
100	PERCENT TOTAL

TV= 3672.5 DEGREES K

N= .037145 MOLES/GRAM

F= 379506. FT-LB/LB

CV= 468.777 FT-LB/LB-DEG K

GAMMA= 1.22044

ETA= 26.6058 CU-IN/LB

..

HES 5250.200

1.	PERCENT BARIUM NITRATE	
6.5	PERCENT ETHYL CENTRALITE, CARBAMITE	
.2	PERCENT GRAPHITE	
71.3	PERCENT NITROCELLULOSE	13.25 PERCENT N
20.	PERCENT NITROGLYCERINE	
1.	PERCENT POTASSIUM NITRATE	
100	PERCENT TOTAL	

TV= 3110.67 DEGREES K

N= .041068 MOLES/GRAM

F= 355398. FT-LB/LB

CV= 474.846 FT-LB/LB-DEG K

GAMMA= 1.24061

ETA= 28.7144 CU-IN/LB

..

HES 5250.201

1.	PERCENT BARIUM NITRATE
6.5	PERCENT ETHYL CENTRALITE, CARBAMITE
.2	PERCENT GRAPHITE
71.3	PERCENT NITROCELLULOSE 13.25 PERCENT N
20.	PERCENT NITROGLYCERINE
1.	PERCENT POTASSIUM NITRATE
100	PERCENT TOTAL

TV= 3110.67 DEGREES K

N= .041068 MOLES/GRAM

F= 355398. FT-LB/LB

CV= 474.846 FT-LB/LB-DEG K

GAMMA= 1.24061

ETA= 28.7144 CU-IN/LB

..

HES 5250.202

1.	PERCENT BARIUM NITRATE
6.5	PERCENT ETHYL CENTRALITE, CARBAMITE
.2	PERCENT GRAPHITE
71.3	PERCENT NITROCELLULOSE 13.25 PERCENT N
20.	PERCENT NITROGLYCERINE
1.	PERCENT POTASSIUM NITRATE
100	PERCENT TOTAL

TV= 3110.67 DEGREES K

N= .041068 MOLES/GRAM

F= 355398. FT-LB/LB

CV= 474.846 FT-LB/LB-DEG K

GAMMA= 1.24061

ETA= 28.7144 CU-IN/LB

..

HES 5250.203

1.	PERCENT BARIUM NITRATE	
6.5	PERCENT ETHYL CENTRALITE, CARBAMITE	
.2	PERCENT GRAPHITE	
71.3	PERCENT NITROCELLULOSE	13.25 PERCENT N
20.	PERCENT NITROGLYCERINE	
1.	PERCENT POTASSIUM NITRATE	
100	PERCENT TOTAL	

TV= 3110.67 DEGREES K

N= .041068 MOLES/GRAM

F= 355398. FT-LB/LB

CV= 474.846 FT-LB/LB-DEG K

GAMMA= 1.24061

ETA= 28.7144 CU-IN/LB

..

HES 5354-26A

1.5	PERCENT BARIUM NITRATE	
.6	PERCENT ETHYL CENTRALITE, CARBAMITE	
.25	PERCENT GRAPHITE	
77.35	PERCENT NITROCELLULOSE	13.25 PERCENT N
19.5	PERCENT NITROGLYCERINE	
.8	PERCENT POTASSIUM NITRATE	
100	PERCENT TOTAL	

TV= 3662.61 DEGREES K

N= 3.71752E-2 MOLES/GRAM

F= 378792. FT-LB/LB

CV= 468.588 FT-LB/LB-DEG K

GAMMA= 1.22071

ETA= 26.6281 CU-IN/LB

..

HIVEL #2 (ALSO SEE HES 4831.9B AND M-2)

1.5	PERCENT BARIUM NITRATE	
.6	PERCENT ETHYL CENTRALITE, CARBAMITE	
.25	PERCENT GRAPHITE	
77.35	PERCENT NITROCELLULOSE	13.15 PERCENT N
19.5	PERCENT NITROGLYCERINE	
.8	PERCENT POTASSIUM NITRATE	
100	PERCENT TOTAL	

TV= 3627.71 DEGREES K

N= 3.73439E-2 MOLES/GRAM

F= 376886. FT-LB/LB

CV= 469.278 FT-LB/LB-DEG K

GAMMA= 1.22138

ETA= 26.7055 CU-IN/LB

..

IMR 5010 LOT 255

.62	PERCENT ACETONE	
8.99	PERCENT DINITROTOLUENE	
.6	PERCENT DIPHENYLAMINE	
88.14	PERCENT NITROCELLULOSE	13.16 PERCENT N
.7	PERCENT POTASSIUM SULPHATE	
.95	PERCENT WATER	
100	PERCENT TOTAL	

TV= 2891.68 DEGREES K

N= 4.17095E-2 MOLES/GRAM

F= 335539. FT-LB/LB

CV= 477.759 FT-LB/LB-DEG K

GAMMA= 1.24287

ETA= 28.9646 CU-IN/LB

..

IND 7199 (ALSO IOW 7199)

2.88	PERCENT DIBUTYL PHTHALATE		
9.59	PERCENT DINITROTOLUENE		
.86	PERCENT DIPHENYLAMINE		
86.67	PERCENT NITROCELLULOSE	13.16	PERCENT N
100	PERCENT TOTAL		

TV= 2727.14 DEGREES K

N= 4.34383E-2 MOLES/GRAM

F= 329562. FT-LB/LB

CV= 476.693 FT-LB/LB-DEG K

GAMMA= 1.25351

ETA= 29.9593 CU-IN/LB

..

M-2 (ALSO SEE HVEL #2 AND HES 4831.9B)

1.5	PERCENT BARIUM NITRATE
.6	PERCENT ETHYL CENTRALITE, CARBAMITE
.25	PERCENT GRAPHITE
77.35	PERCENT NITROCELLULOSE 13.15 PERCENT N
19.5	PERCENT NITROGLYCERINE
.8	PERCENT POTASSIUM NITRATE
100	PERCENT TOTAL

TV= 3627.71 DEGREES K

N= 3.73439E-2 MOLES/GRAM

F= 376886. FT-LB/LB

CV= 469.278 FT-LB/LB-DEG K

GAMMA= 1.22138

ETA= 26.7055 CU-IN/LB

..

M-5

1.4	PERCENT BARIUM NITRATE		
.6	PERCENT ETHYL CENTRALITE, CARBAMITE		
.3	PERCENT GRAPHITE		
81.95	PERCENT NITROCELLULOSE	13.25	PERCENT N
15.	PERCENT NITROGLYCERINE		
.75	PERCENT POTASSIUM NITRATE		
100	PERCENT TOTAL		

TV= 3569.32 DEGREES K

N= 3.76096E-2 MOLES/GRAM

F= 373457. FT-LB/LE

CV= 468.764 FT-LB/LB-DEG K

GAMMA= 1.2232

ETA= 26.8693 CU-IN/LB

..

N-4

10.6	PERCENT DIETHYL PHTHALATE	
.5	PERCENT LEAD STEARATE	
51.	PERCENT NITROCELLULOSE	12.6 PERCENT N
2.	PERCENT 2-NITRODIPHENYLAMINE	
34.3	PERCENT NITROGLYCERINE	
1.5	PERCENT POTASSIUM SULPHATE	
.1	PERCENT CARBON	
100	PERCENT TOTAL	

TV= 2845.93 DEGREES K

N= 4.26239E-2 MOLES/GRAM

F= 337469. FT-LB/LB

CV= 484.815 FT-LB/LB-DEG K

GAMMA= 1.24459

ETA= 27.819 CU-IN/LB

..

NPFB 292 (ALSO SPDN 10387)

3.07	PERCENT DIBUTYL PHTHALATE		
10.25	PERCENT DINITROTOLUENE		
.64	PERCENT DIPHENYLAMINE		
.66	PERCENT ETHYL ALCOHOL		
83.83	PERCENT NITROCELLULOSE	13.15	PERCENT N
1.55	PERCENT WATER		
100	PERCENT TOTAL		

TV= 2566.39 DEGREES K

N= 4.42701E-2 MOLES/GRAM

F= 316075. FT-LB/LB

CV= 485.875 FT-LB/LB-DEG K

GAMMA= 1.25348

ETA= 30.1697 CU-IN/LB

..

PYROCELLULOSE

.46	PERCENT DIPHENYLAMINE		
5.71	PERCENT ETHYL ALCOHOL		
93.79	PERCENT NITROCELLULOSE	12.63	PERCENT N
.04	PERCENT WATER		
100	PERCENT TOTAL		

TV= 2552.07 DEGREES K

N= 4.45196E-2 MOLES/GRAM

F= 316083. FT-LB/LB

CV= 501.226 FT-LB/LB-DEG K

GAMMA= 1.2471

ETA= 29.8647 CU-IN/LB

..

SPDN 8880

5.12	PERCENT DIBUTYL PHTHALATE	
10.25	PERCENT DINITROTOLUENE	
1	PERCENT DIPHENYLAMINE	
.28	PERCENT ETHYL ALCOHOL	
81.86	PERCENT NITROCELLULOSE	13.13 PERCENT N
.85	PERCENT POTASSIUM SULPHATE	
.64	PERCENT WATER	
100	PERCENT TOTAL	

TV= 2407.87 DEGREES K

N= .044939 MOLES/GRAM

F= 301032. FT-LB/LB

CV= 482.736 FT-LB/LB-DEG K

GAMMA= 1.25698

ETA= 30.6661 CU-IN/LB

..

SPDN 9373 (ALSØ CDPB-LNH)

3.15	PERCENT DIBUTYL PHTHALATE		
10.48	PERCENT DINITROTØULENE		
1.03	PERCENT DIPHENYLAMINE		
.63	PERCENT ETHYL ALCOHØL		
84.01	PERCENT NITRØCELLULOSE	13.15	PERCENT N
.7	PERCENT WATER		
100	PERCENT TØTAL		

TV= 2564.42 DEGREES K

N= 4.44675E-2 MØLES/GRAM

F= 317242. FT-LB/LB

CV= 482.347 FT-LB/LB-DEG K

GAMMA= 1.25647

ETA= 30.3871 CU-IN/LB

..

UNIQUE (ALSO BULLSEYE)

1.	PERCENT ETHYL CENTRALITE, CARBAMITE
.25	PERCENT GRAPHITE
58.85	PERCENT NITROCELLULOSE 13.25 PERCENT N
39.9	PERCENT NITROGLYCERINE
100	PERCENT TOTAL

TV= 4021.31 DEGREES K

N= 3.64779E-2 MOLES/GRAM

F= 408089. FT-LB/LB

CV= 474.21 FT-LB/LB-DEG K

GAMMA= 1.214

ETA= 26.0266 CU-IN/LB

..

VIII. RECOMMENDATIONS

The computer program discussed is a useful tool for the interior ballisticians engaged in simulation of CADs, guns, and other ballistic systems. It minimizes the time spent and chance of error in performing these tedious calculations on new propellants. As time permits, the additive constants should be determined for new propellants being developed. In addition, experimental determination of the ballistic properties of propellants should be conducted to verify, or perhaps modify, the calculated data.

IX. BIBLIOGRAPHY

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APPENDIX A

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UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)		2a. REPORT SECURITY CLASSIFICATION	
Naval Weapons Laboratory Dahlgren, Virginia 22448		UNCLASSIFIED	
3. REPORT TITLE		2b. GROUP	
A COMPUTER PROGRAM TO CALCULATE THERMAL AND BALLISTIC PROPERTIES OF SOLID PROPELLANTS			
4. DESCRIPTIVE NOTES (Type of report and, inclusive dates)			
5. AUTHOR(S) (First name, middle initial, last name)			
William J. Brown			
6. REPORT DATE		7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
July 1973			
8a. CONTRACT OR GRANT NO.		9a. ORIGINATOR'S REPORT NUMBER(S)	
b. PROJECT NO.		NWL TR-3007	
c.		9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.			
10. DISTRIBUTION STATEMENT			
Distribution limited to U.S. Gov't. agencies only; Test and Evaluation; July 1973. Other requests for this document must be referred to the Commander, Naval Weapons Laboratory, Dahlgren, Virginia 22448.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY	
13. ABSTRACT			
This report describes a computer program written to calculate ballistic and thermal properties of solid propellants using the method of additive constants. A program listing and sample output are included.			